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Citation: AIP Conf. Proc. **1531**, 119 (2013); doi: 10.1063/1.4804722
View online: http://dx.doi.org/10.1063/1.4804722
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1531&Issue=1
Published by the American Institute of Physics.

Intercomparison of Three Microwave/Infrared High Resolution Line-by-line Radiative Transfer Codes

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Abstract. An intercomparison of three line-by-line (lbl) codes developed independently for atmospheric sounding — ARTS, GARLIC, and KOPRA — has been performed for a thermal infrared nadir sounding application assuming a HIRS-like (High resolution Infrared Radiation Sounder) setup. Radiances for the HIRS infrared channels and a set of 42 atmospheric profiles from the "Garand dataset" have been computed. Results of this intercomparison and a discussion of reasons of the observed differences are presented.

Keywords: Line-by-line, Infrared, HIRS channels, Garand atmospheres, Intercomparisons.
PACS: 42.68Ay, 42.68Ca, 92.60Vb

INTRODUCTION

Line-by-line (Lbl) modeling of atmospheric radiative transfer is essential for the analysis of a growing number of high resolution infrared (IR) and microwave remote sensing instruments. Because the quality of retrieval products critically depends on the accuracy of the radiative transfer codes used as forward model in the inversion process, verification and validation of these codes is crucial, and hence several code intercomparisons have been performed.

In this contribution we present an intercomparison of three Lbl codes developed independently for atmospheric sounding: ARTS, GARLIC (MIRART) and KOPRA. Note that ARTS – MIRART and KOPRA – MIRART intercomparisons (including some other models) have already been performed in the context of the "Third International Radiative Transfer Modeling Workshop" and the AMIL2DA project, respectively [1, 2].

THE CODES

The intensity (radiance) I at wavenumber ν seen at position s = 0 is described by the equation of radiative transfer

$$I(\nu) = I_b\,(\nu) e^{-\tau(\nu,s)} + \int_0^\tau B(\nu,T) e^{-\tau'} d\tau' \qquad (1)$$

where I_b is a background contribution and B is the Planck function at temperature T. In case of only molecular absorption the optical depth is modeled by

$$\tau(\nu,s) = \int_0^s ds' \sum_m n_m\,(s') \sum_l S_l^m\, g\left(\nu, \nu_{lm}, \gamma_{lm}\big(p(s'), T(s')\big)\right) \qquad (2)$$

where n_m is the number density of molecule m and the absorption cross section is obtained by summing over the contributions from many lines at position ν_{lm} described by the product of the temperature–dependent line strength S_{lm} and a normalized line shape function g describing the combined effect of pressure and Doppler broadening (i.e. a Voigt profile).

Radiation Processes in the Atmosphere and Ocean (IRS2012)
AIP Conf. Proc. 1531, 119-122 (2013); doi: 10.1063/1.4804722

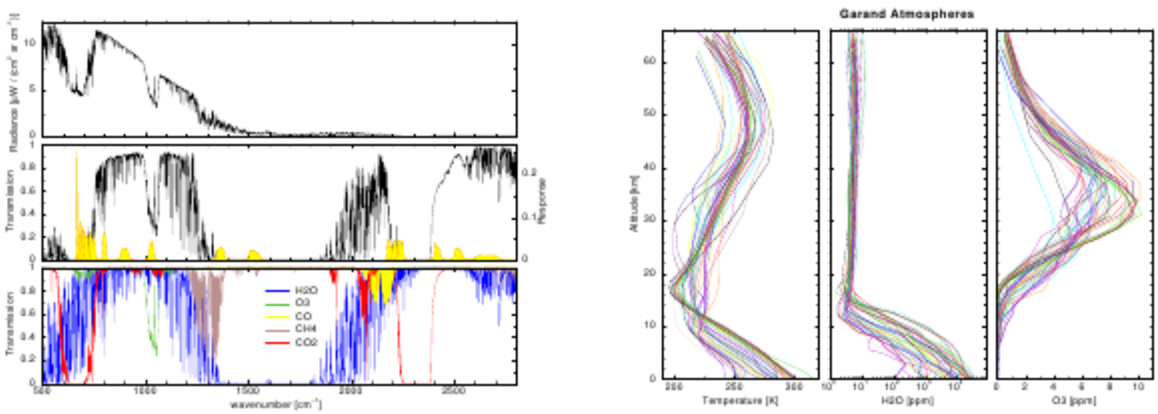

FIGURE 1. a) Top-of-atmosphere radiance and transmissions and the 19 HIRS channels. b) Temperature, H_2O, and O_3 profiles of the 42 Garand atmospheres.

ARTS — Atmospheric Radiative Transfer Simulator

ARTS is a public domain project initiated and developed jointly by the University of Bremen and Chalmers University, Gothenburg [3, 4]; see also http://www.sat.ltu.se/arts/. It has originally focused on microwave applications with uplooking (MIAWARA, AMSOS), downlooking (Advanced Microwave Sounding Unit AMSU-B, Microwave Humidity Sounder MHS) and limb viewing instruments (ODIN, Superconducting Submillimeter-Wave Limb-Emission Sounder SMILES).

GARLIC — Generic Atmospheric Radiation Line-by-line Infrared Code

GARLIC is the modern Fortran90 re-implementation of MIRART, originally designed for far and mid IR applications [5] with arbitrary observation geometries, instrumental field of view and spectral response functions. Among others it has been used to simulate and analyze limb observations with MIPAS and TELIS (TeraHertz Limb Sounder), and thermal and near IR nadir spectra of AIRS, IASI, and SCIAMACHY. Recently it has also been applied to (exo-)planet atmospheric studies, e.g. to model Venus observations from ground-based or spaceborne (SCIAMACHY) instruments.

KOPRA — Karlsruhe Optimized & Precise Radiative transfer Algorithm

KOPRA is a line-by-line, layer-by-layer model for forward calculation of infrared atmospheric transmittance and radiance spectra for various geometries and was specifically developed for the analysis of MIPAS mid infrared limb emission sounder data [6]. It is used for retrievals of limb and uplooking instruments observing thermal emission and solar absorption spectra (MIPAS (Michelson Interferometer for Passive Atmospheric Sounding, aboard Envisat, balloon, or aircraft), GLORIA or ground based FTIR).

SET-UP

In this intercomparison we consider a thermal infrared nadir sounding application and model the upwelling radiation seen by a spaceborne, vertically downlooking observer. In particular we use a HIRS (High resolution Infrared Radiation Sounder) setup and compute radiances for its 19 channels (Fig. 1a) and a set of 42 atmospheric profiles (the Garand et al. [7] dataset, comprising pressure, temperature, water vapor, carbon dioxide, ozone etc., Fig. 1b) representative of most meteorological situations. Absorption of the main molecular absorbers in the IR is considered (H_2O, CO_2, O_3, CH_4, N_2O, and CO) with line spectroscopic data taken from the HITRAN database [8]. Continuum contributions, nb. the (MT)-CKD continuum, were also taken into account.

RESULTS AND DISCUSSION

The radiance spectra (i.e. the monochromatic spectra convolved with the HIRS channel functions) converted to equivalent brightness temperatures are depicted in Fig. 2 for the first half of the 42 Garand atmospheres. Differences are hardly visible in this representation. A detailed analysis of brightness temperature differences reveals that discrepancies for most channels are in the sub-Kelvin range, whereas larger deviations of up to a few Kelvin are observed for a few channels (Fig. 3).

Largely there is good agreement among ARTS, GARLIC, and KOPRA with differences in the same magnitude as reported for the lbl models participating in the Garand et al. [7] study. Discrepancies in some channels are currently under investigation, potential reasons discussed comprise: continua (H_2O, CO_2 ,… , notably different versions of the (MT-)CKD continuum); different line strength conversion schemes; various lbl optimization schemes (wing truncation, weak line rejection, …); evaluation of path integrals; etc. A detailed analysis of these issues will be presented in a forthcoming paper.

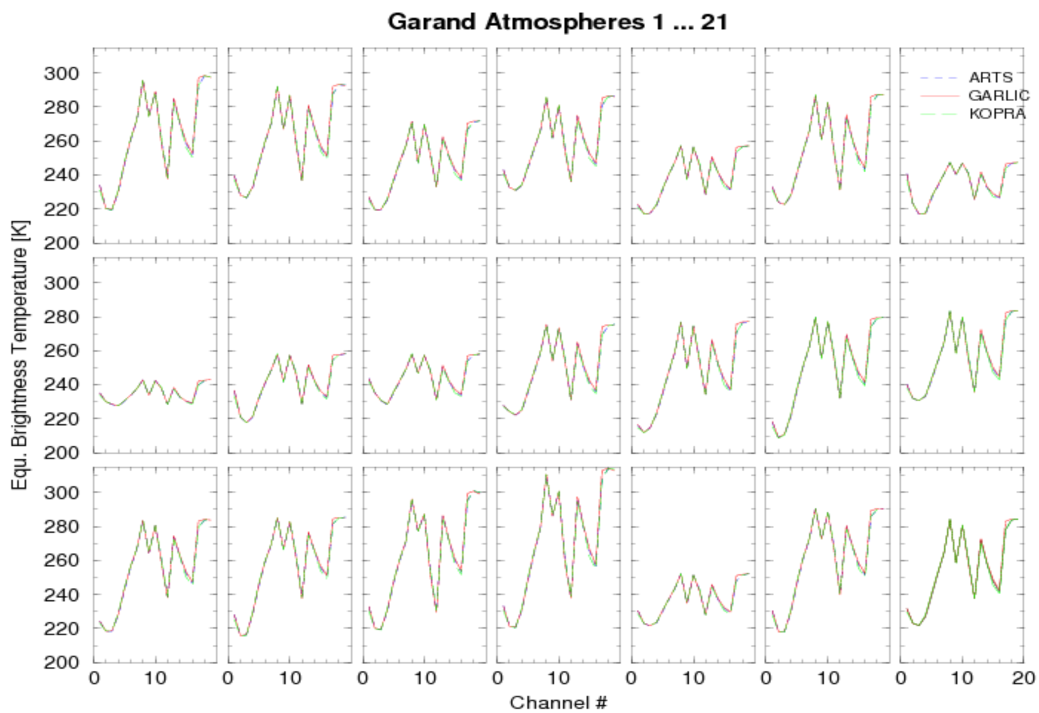

FIGURE 2. Equivalent brightness temperatures as a function of channel number (essentially central wavenumber) for the first 21 (of 42) atmospheres.

ACKNOWLEDGMENTS

F. S. would like to thank Jana Mendrok and Stefan Bühler for funding a short stay in Kiruna.

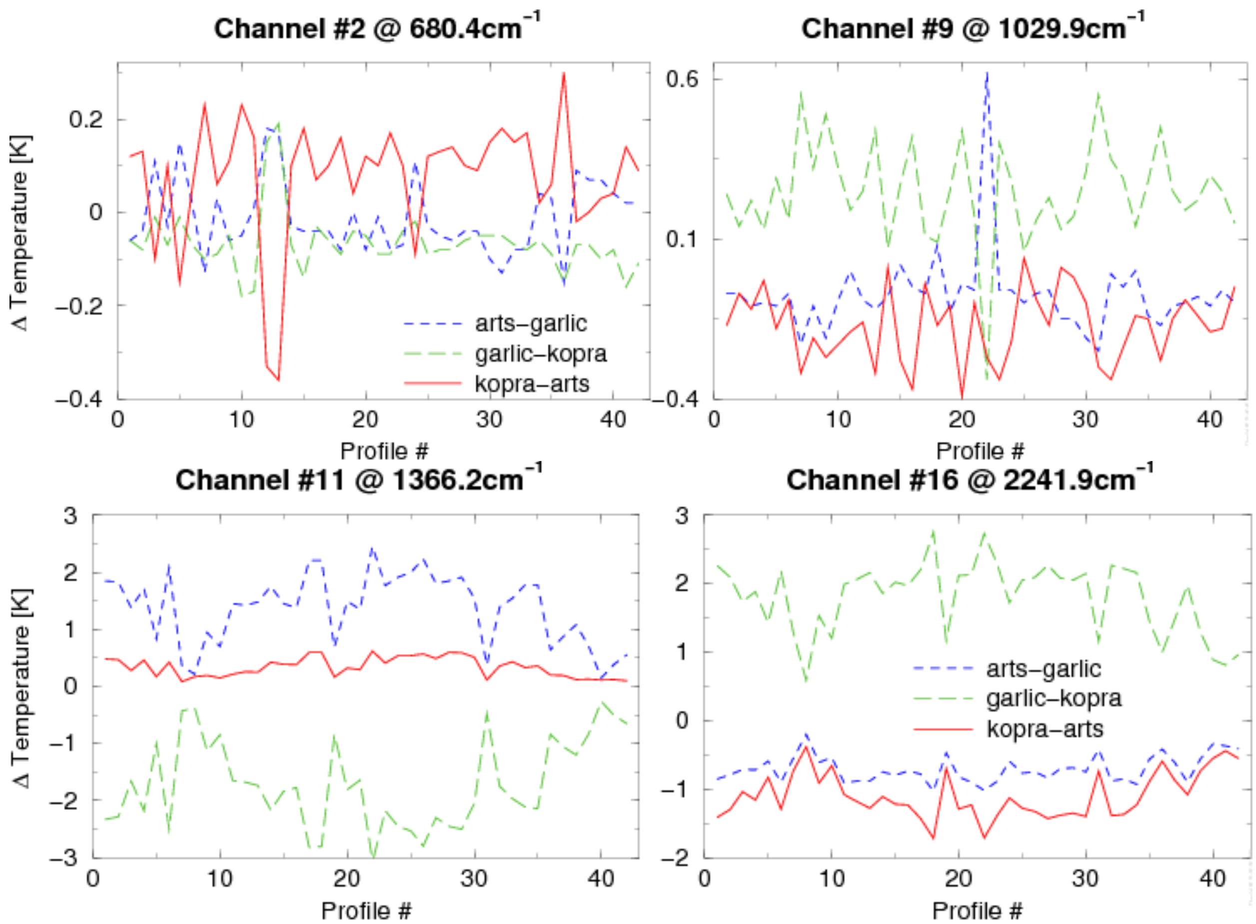

FIGURE 3. Difference brightness temperatures as a function of profile number for 4 selected channels.

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